Chen et al. BMC Geriatrics (2025) 25:38
https://doi.org/10.1186/s12877-025-05687-1

BMC Geriatrics

RESEARCH Open Access

Physical activity, Vitamin D, and all-cause/cardiovascular mortality: a prospective study in older Chinese adults

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Abstract

Background Physical activity was associated with the risk of all-cause and cardiovascular mortality. However, little is known about older adults, especially those aged over 80 years.

Methods 2863 older adults in the Chinese Longitudinal Healthy Longevity Survey (CLHLS) were enrolled. Physical activity score was used to evaluate the physical activity. Serum 25-hydroxyvitamin D and demographic characteristics were collected at baseline. We used multivariable-adjusted Cox regression models and stratified analysis to determine the association between physical activity, vitamin D and all-cause/cardiovascular mortality. Mediation analysis was performed to evaluate the mediating effect of vitamin D between physical activity and all-cause/cardiovascular mortality.

Results The median age of this population was 87 years, and 70.27% were the oldest-old (age ≥ 80 years). We observed a tendency for a higher vitamin D concentration in participants with higher physical activity score levels. Both physical activity and vitamin D levels were inversely associated with all-cause and cardiovascular mortality in all participants. Between physical activity and all-cause/cardiovascular mortality, the mediation proportions of vitamin D were 7.76% ($P < 0.001$) and 4.13% ($P < 0.001$), respectively. The mediating effect of vitamin D remained all significant in various types of physical activities. Furthermore, vitamin D accounted for a greater mediating proportion in the physical activities of housework and raising domestic animals/pets.

Conclusions Physical activity could reduce the risk of all-cause/cardiovascular mortality and was mediated by vitamin D in older Chinese adults.

Keywords Physical activity, Vitamin D, Older adults

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Introduction

There is a growing interest in the function of physical activity in improving health. Previous studies summarized that physical activity was associated with a lower risk of all-cause and cardiovascular mortality [1, 2]. The 2020 World Health Organization guidelines recommend that adults get 150–300 min per week of moderate-intensity aerobic activity, 75–150 min of vigorous-intensity aerobic activity, or an equivalent combination of both [3]. However, vigorous exercise is difficult in older adults, especially the oldest-old (age ≥ 80 years). Some research discovered that mild-intensity physical activity could also reduce the risk of all-cause/cardiovascular and cancer mortality [4, 5]. Nevertheless, the extent of the health benefits of physical activity for older adults remains largely unexplored.

The relationship between physical activity and all-cause/cardiovascular mortality is promoted by multiple mechanisms [6]. Physical activity, especially aerobic exercise, can increase cardiac output and muscle oxygen uptake to improve cardiorespiratory fitness. Physical activity can also improve the endothelial function of the coronary arteries, thereby reducing the risk of cardiovascular disease and mortality. Physical activity has a positive impact on type 2 diabetes, hypertension, and hyperlipidemia, which are all risk factors for cardiovascular disease. Improving blood sugar control, enhancing the body's response to insulin, and reducing adipose tissue, especially visceral abdominal fat, reduces the risk of cardiovascular diseases and mortality. Vitamin D is vital in maintaining skeletal health and has been discovered to safeguard against cardiovascular diseases, metabolic syndrome, infections, autoimmune diseases, cancer, etc [7, 8]. About 90% of vitamin D is synthesized in the skin under ultraviolet light exposure, while the sources of vitamin D from food are minimal [9, 10]. This unique synthesis pathway leads to seasonal fluctuations in vitamin D levels. Moreover,

some studies have also shown that serum vitamin D levels increase indoors and outdoors, especially outdoors, as outdoor activities are usually associated with sun exposure, an important part of physical activity [11]. Vitamin D, once transported by the vitamin D binding protein within the bloodstream, undergoes a process of 25-hydroxylation in the liver, resulting in its activation into 25-hydroxyvitamin D (25 (OH)D) [12]. 25 (OH)D is the primary circulating form of vitamin D, and its concentration is considered one of the most robust biomarkers for assessing vitamin D status [13]. Observational research has demonstrated that higher serum levels of 25 (OH)D are associated with lower blood pressure, reduced risk of cardiovascular disease, and decreased all-cause mortality among adults [14]. However, the complex relationship between physical activity, vitamin D, and all-cause/cardiovascular mortality among older adults needs more evidence for a better understanding.

Few studies have explored the connection between physical activity and vitamin D levels [11, 15]. Additionally, there is a shortage of older population-based research from developing countries, and further studies are required. Therefore, we analyzed the data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS), aiming to investigate the association between physical activity and all-cause/cardiovascular mortality and the mediating role of vitamin D among older adults.

Methods

Study population

The study population was obtained from CLHLS, a nationwide study of community-dwelling older individuals from 23 provinces and autonomous regions in China since 1998. In 2011 and 2014, additional research was undertaken in eight longevity areas (Xiayi County, Laizhou City, Mayang County, Zhongxiang City, Sanshui District, Yongfu County, Rudong County, and Chengmai County) to gather a broader range of physical examinations and obtain blood samples. A comprehensive description and evaluation of the CLHLS has been previously documented [16]. Extensive information was gathered through face-to-face interviews, including socio-demographic characteristics and physical and cognitive health statuses. The current analyses are based on data from the 2011 and 2014 waves of the CLHLS. In the 2011 wave, 9765 potential participants were enrolled. In the 2014 wave, 7292 participants were enrolled, and 1126 were new. 7366 participants who did not take a blood test were excluded, and the remaining 3523 participants underwent the blood test. In the 2014 and 2018 follow-up waves, survival data was documented. Due to inconclusive survival duration, those not followed up or with invalid death records ($n = 628$) were excluded. As a result, there were 2897 participants with complete survival information. Screening the data, we excluded participants below 60 years ($n = 26$) and with a BMI greater than 50 or less than 10 ($n = 9$), probably caused by human error in record keeping. Multiple imputation was used for missing data. At last, there were 2863 participants for the subsequent study.

Figure 1 shows the recruitment process. The CLHLS obtained approval from the Ethics Committee of Peking University (IRB00001052–13074). Before the face-to-face interview, all participants or their legally authorized representatives provided written informed consent.

Exposure

Physical activity score

Proficiently trained researchers evaluated activity-related factors at baseline via a questionnaire [17, 18]. We

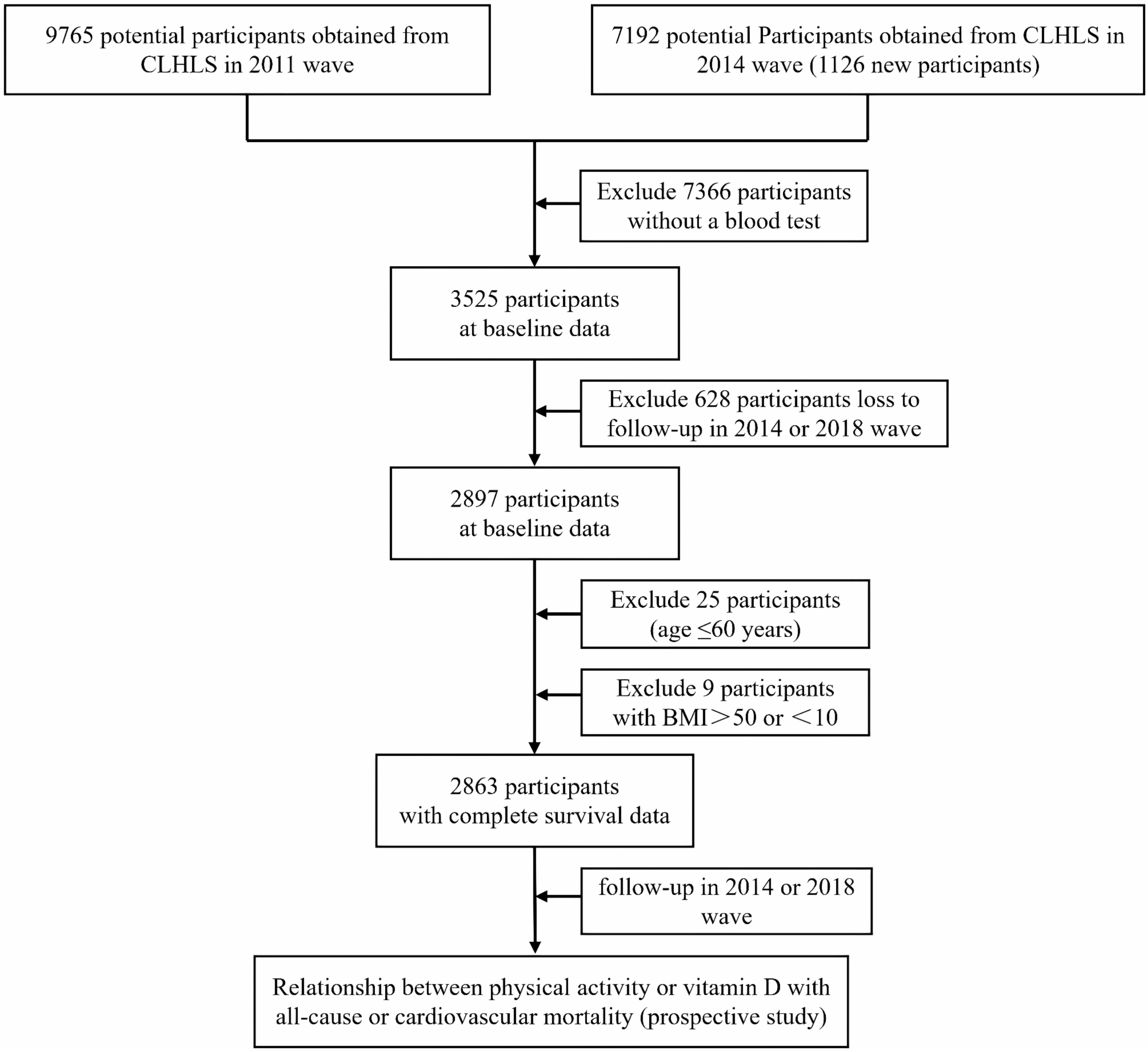

Fig. 1 Flow chart of the study selection process

conducted a physical activity score through regular exercise and activities [19, 20]. The regular activities included 8 aspects. We chose 4 aspects: housework, growing vegetables/other fieldwork, gardenwork, and raising domestic animals/pets as physical activity. Reading newspapers/books, playing cards/mah-jong, watching TV/listening to radio, and social activities were excluded. All the activities were assessed by frequency, with the criteria that 'almost every day' was scored as 2, 'once a week or a month' was scored as 1, and 'rarely or never' was scored as 0 (Supplementary Table S1). The sum of the scores above was defined as a physical activity score and was regarded as a categorical and continuous variable. For categorical variables, the physical activity score was divided into three groups by tertiles: low (0–1), median (2–4), and high (5–10).

Assessments of vitamin D status

All participants had 5 ml of venous blood collected after an overnight fast, and the samples were placed in heparin-anticoagulated blood collection tubes and sent for routine blood tests. An enzyme-linked immunosorbent assay system (ELISA), originating from Bolton, UK, measured the concentration of 25(OH)D with variations below 8% and 10% for intra- and inter-assays [21]. In our study, we assessed vitamin D status by 25(OH) D and treated it in terms of tertiles and as a continuous variable. For tertiles, vitamin D status was grouped into low

(<29.57nmol/L), median(29.57nmol/L-45.74nmol/L), and high(>45.74nmol/L).

Outcome

The outcome of our study was both all-cause and cardiovascular mortality. All the survival data was obtained through a follow-up every four years, and information regarding the deaths was gathered from their next of kin or local/community healthcare providers, along with official death certificates when possible (verified through hospital admissions and medical documentation) [18, 22]. Data on mortality have been validated elsewhere [23]. The survival time was defined as the observation period, calculated as the span from the initial interview to the most recent valid follow-up survey or the occurrence of death. Death from hypertension, heart disease, stroke, and dyslipidemia was defined as cardiovascular mortality. Cardiovascular disease (CVD) mortality was documented using the international classification of diseases (ICD-10) codes, specifically the codes I00-I99, which comprehensively cover a wide range of cardiovascular diseases.

Covariates

Baseline measurements of age, sex, drinking, smoking, diet, residence, marital status, income, body mass index (BMI), self-reported health conditions, and activity of daily living (ADL) were collected as covariates. Smoking and drinking were divided into smoking/drinking or not. Fruit, vegetables, meat, fish, egg, milk, beans, tea, and nuts were included to assess the diet (Supplementary Table S2). The assessment was similar to the physical activity score, and ideal diet intake was defined as the top 40% of the score, in line with the former study [24]. Residence included "city/town" and "rural areas". Marital status was defined as "alone" and "not alone" based on the current marital status. Income was categorized as less than 10,000 yuan and more than 10,000 yuan per year. BMI was computed as weight (in kilograms)/ height^2 (in meters squared) and categorized as normal weight (<24) and overweight (≥24). Self-reported health conditions include whether an individual has diabetes, hypertension, stroke, or heart disease. Similar to a formerly published article, ADL was calculated by bathing, dressing, toileting, indoor moving, continence of defecation, and eating (Supplementary Table S3). Each aspect was categorized into complete independence (scored 1), partial independence (scored 2), and complete dependence (scored 3). Participants were classified as impaired if they exhibited "complete dependence" on any aspect of the ADL [25].

Statistical analysis

Baseline data for different groups were analyzed according to physical activity score. Continuous variables were presented as median with the interquartile range (IQR) for skewed distributions. Categorical variables were represented as counts and corresponding percentages. Variance analysis, Kruskal-Wallis, and Chi-square tests were applied to evaluate differences in proportions across groups. Additionally, treated as a continuous variable, physical activity score and vitamin D were further measured by restricted cubic splines. To assess the relationship between physical activity, vitamin D, and all-cause/cardiovascular mortality, we utilized multivariable-adjusted Cox regression models to estimate the hazard ratio (HR) with a 95% confidence interval (CI). Three models were constructed: Model 1, which was unadjusted; Model 2, adjusted for sex and age; and Model 3, further adjusted for smoking, drinking, diet, residence, income, marital status, BMI, ADL as well as the presence of hypertension, diabetes, heart disease, and stroke. The proportional hazards assumption was verified through Schoenfeld residual tests ($p>0.05$). Restricted cubic splines were also adopted to assess the risk based on the smallest Akaike's information criterion. We further explored a mediation analysis to evaluate the mediation effect of vitamin D in the role of physical activity on all-cause and cardiovascular mortality by a 2-stage regression method [26]. In brief, physical activity served as a predictor model (X), vitamin D status served as the mediator (M), and all-cause/cardiovascular mortality served as the outcome (Y). The analysis was achieved as follows: (1) the total effect of physical activity on the outcome ($Y=\beta_{Total}\ X$); (2) The association effect of physical activity on vitamin D ($M=\beta_1\ X$); (3) The effect of both physical activity and vitamin D on the outcome ($Y=\beta_{Dir}\ X+\beta_2\ M$). The mediation proportion (%) was calculated as ($\beta_{Indir}/\beta_{Total}$) $\times100\%=(\beta_1\times\beta_2)/\ \beta_{Total}\times100\%$. This method was in line with a former study [27].

To further verify our study, sensitive and subgroup analysis were performed by following steps: (1) setting chronological age instead of observation time as the timescale in the Cox model; (2) conducting stratified analysis in sex, marital status, income, residence, BMI, ADL, smoking, drinking, and diet to detect the significance in different subgroups and their interactions; (3) further subdivided the physical activity into regular exercise, housework, gardenwork, growing vegetables/other fieldwork, and raising domestic animals/pets to explore their respective mediating effects of vitamin D.

All statistical analysis were performed using the R software package (version 4.3.2), with a significance level set at a P value<0.05 for both-sided tests.

Results

Baseline characteristics of participants

Between Jan 1, 2011, and Dec 31, 2018, 2863 older adults in CLHLS were included during a median follow-up of

3.44 years (IQR 1.93–5.35; 9698.9 person-years). The median survival time of the study population was 1254 days (IQR 703.5–1953.0). Table 1 presented the demographics and clinical characteristics of all participants. The population's median age was 87 years old, and 70.27% were the oldest-old. There were 638 older adults over 100 years old. Women accounted for 55.85% of the total population. According to the tertiles of physical activity score, the population was divided into low group (0–1), median group (2–4), and high group (5–10). As shown in Table 1, age, the proportion of females, current smoking status, current drinking status, the proportion of the ideal diet, marital status, income, BMI, the proportion of ADL impairment, and the morbidity of stroke or diabetes were significantly different among these three groups. No differences were detected in the morbidity of hypertension or heart disease. The concentration of vitamin D in the high physical activity group (42.10 nmol/L) was significantly higher compared to the low group (29.59 nmol/L, $P<0.0001$) and median group (39.46 nmol/L, $P<0.01$) (Fig. 2A). After adjusting for age, sex, drinking, smoking, diet, residence, income, marital status, body mass index, ADL, morbidity of hypertension, diabetes, heart disease, and stroke, we found a tendency for higher concentrations of vitamin D in participants with higher physical activity score levels (Fig. 2B).

Physical activity and all-cause/cardiovascular mortality

The survival time in the high physical activity score was significantly longer than in the low and median groups (Supplementary Fig. S1A). The result of the association between physical activity and all-cause/cardiovascular mortality is shown in Table 2. For the categorical variable, physical activity was divided into three groups by tertiles: low (0–1), median (2–4) and high (5–10). Model 1 was unadjusted, Model 2 was adjusted for age and sex, and Model 3 was adjusted for all the variables in Model 2 plus drinking, smoking, diet, residence, income, marital status, BMI, ADL, morbidity of hypertension, diabetes, heart disease, and stroke. With the increase in physical activity levels, all-cause and cardiovascular mortality continued to decrease in all three models. After adjusting for all the variables in Model 3, median physical activity could reduce all-cause mortality by 23% (HR: 0.77, 95%CI: 0.67–0.88) and cardiovascular mortality by 17% (HR: 0.83, 95%CI: 0.66–1.03) compared to the low physical activity group. High physical activity was associated with a 54% (HR: 0.46, 95%CI: 0.37–0.57) reduction in all-cause mortality and a 52% (HR: 0.48, 95%CI: 0.34–0.67) decrease in cardiovascular mortality. Significance remained after setting chronological age instead of observation time as the timescale (Table 4). Nonlinearity was also detected between physical activity and all-cause/cardiovascular mortality, with an increasing physical activity score indicating a lower HR (Fig. 3A, B).

Stratified and interaction analysis were performed to more comprehensively assess the relationship between physical activity and all-cause or cardiovascular mortality across different subgroups (Fig. 4). After adjusting for age, sex, drinking, smoking, diet, residence, income, marital status, BMI, ADL, morbidity of hypertension, diabetes, heart disease, and stroke, except the strata variable,

Table 1 Baseline characteristics of the study population by physical activity score tertile

Demographic characteristic			Physical activity groups		
	Total	Low(0–1)	Median(2–4)	High(5–10)	p value
	(*n*=2863)	**(*n*=954)**	**(*n*=1262)**	**(*n*=647)**	
Age(years), median (IQR)	87(77–98)	98(89–101)	84(76–93)	79(71–87)	<0.001
Sex,female(n,%)	1599(55.85%)	642(67.29%)	641(50.79%)	316(48.84%)	<0.001
Drinking (n, %)	601(20.99%)	136(14.26%)	294(23.30%)	171(26.43%)	<0.001
Smoking (n, %)	639(22.32%)	132(13.84%)	322(25.52%)	185(28.59%)	<0.001
Ideal diet (n, %)	1277(44.60%)	362(37.95%)	536(42.48%)	379(58.58%)	<0.001
Residence,rural (n, %)	2320(81.03%)	773(81.03%)	1054(83.52%)	493(76.20%)	<0.001
Marriage,alone (n, %)	1821(63.60%)	792(83.02%)	752(59.59%)	277(42.81%)	<0.001
Income(≤ 10000yuan/year) (n, %)	1419(49.56%)	432(45.28%)	675(53.49%)	312(48.22%)	<0.001
ADL impairment (%)	465(16.24%)	385(40.36%)	70(5.54%)	10(1.55%)	<0.001
Hypertension (n, %)	751(26.23%)	233(24.42%)	343(27.18%)	175(27.05%)	0.298
Diabetes (n, %)	62(2.17%)	15(1.57%)	37(2.93%)	10(1.54%)	0.044
Heart Disease (n, %)	233(8.14%)	71(7.44%)	110(8.72%)	51(8.04%)	0.551
Stroke (n, %)	226(7.89%)	108(11.32%)	87(6.89%)	31(4.79%)	<0.001
BMI (kg/m2), median (IQR)	20.85 (18.07–22.66)	20.08 (18.07–22.66)	20.94 (18.80-23.67)	22.04 (19.84–24.34)	<0.001
Vitamin D(nmol/L), median (IQR)	37.00 (26.32-51.00)	29.59 (21.78–42.18)	39.46 (28.86–54.32)	42.10 (31.51–55.30)	<0.001

BMI, body mass index; interquartile range, IQR; ADL, activity of daily living

Continuous data were described as median (25th to 75th percentiles)

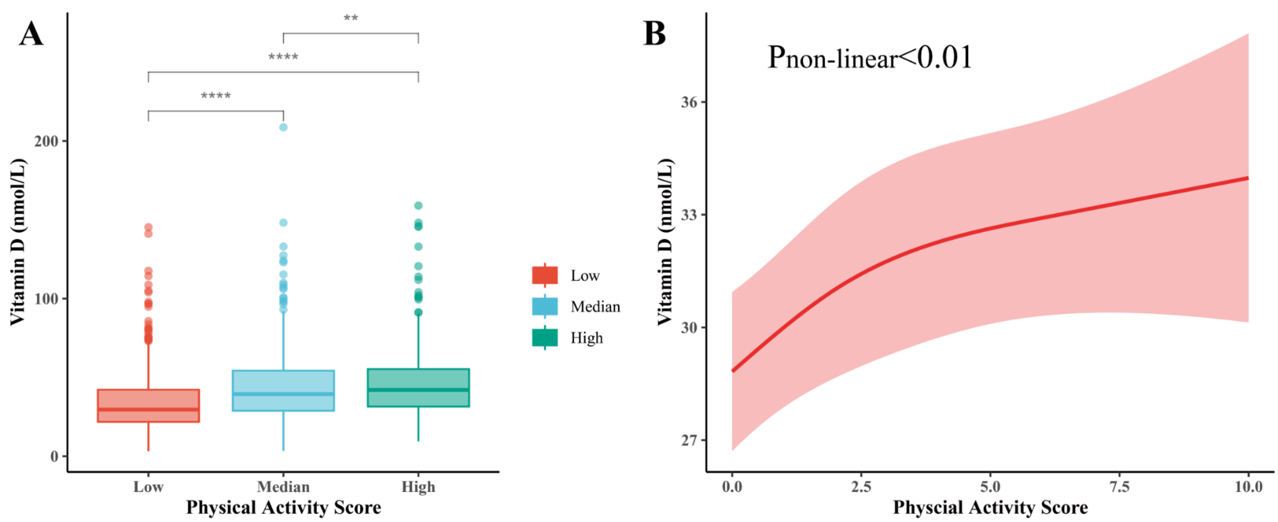

Fig. 2 Vitamin D concentration among three physical activity score groups (****$P<0.0001$, **$P<0.01$) (**A**). Association between physical activity score and vitamin D concentration adjusted for age, sex, drinking, smoking, diet, residence, income, marital status, body mass index, activity of daily living, morbidity of hypertension, diabetes, heart disease, and stroke (**B**)

Table 2 Associations between physical activity groups and all-cause/cardiovascular mortality

Physical activity groups	HR (95%CI)					
	All-cause mortality			Cardiovasular mortality		
	Model1	Model2	Model3	Model1	Model2	Model3
Low (0–1)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Median (2–4)	0.37*** (0.33,0.42)	0.63*** (0.56,0.71)	0.77*** (0.67,0.88)	0.45*** (0.37,0.54)	0.66*** (0.54,0.81)	0.83 (0.66,1.03)
High (5–10)	0.16*** (0.13,0.19)	0.36*** (0.30,0.44)	0.46*** (0.37,0.57)	0.19*** (0.14,0.26)	0.35*** (0.25,0.48)	0.48*** (0.34,0.67)
P for trend	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Model 1 was unadjusted

Model 2 was adjusted for age and sex

Model 3 was adjusted for age, sex, drinking, smoking, diet, residence, income, BMI, ADL, morbidity of hypertension, diabetes, heart disease, and stroke

***$p<0.001$

HR, hazard ratio; CI, confidence interval; BMI, body mass index; ADL, activity of daily living

the association between the high physical activity level and all-cause/cardiovascular mortality remained significant in all subgroups ($P<0.05$). The median physical activity level also showed protective but not all significant effects in reducing all-cause/cardiovascular mortality in most subgroups except BMI ≥ 24.

In interaction analysis, marital status significantly modified the association between physical activity and all-cause mortality. Significance for interaction was also detected in smoking and residence between physical activity and cardiovascular mortality.

Vitamin D and all-cause/cardiovascular mortality

The survival time in the high vitamin D level was significantly longer than in the low and median vitamin D levels (Supplementary Fig. S1B). As shown in Table 3, vitamin D levels were strongly associated with all-cause or cardiovascular mortality in older adults. The adjusted variables of Model 1, Model 2, and Model 3 were the same as above, and low level of vitamin D group acted as a control group. In Model 3, the median vitamin D level could reduce all-cause mortality by 18% (HR: 0.82, 95%CI: 0.72–0.94) and cardiovascular mortality by 6% (HR: 0.94, 95%CI: 0.76–1.16). High level of vitamin D was associated with a 40% (HR: 0.60, 95%CI: 0.51–0.69) reduction in all-cause mortality and 32% (HR: 0.68, 95%CI: 0.53–0.86) in cardiovascular mortality. The results were similar after setting chronological age instead of observation time as the timescale (Table 4). To avoid the loss of potential information and the value of continuity variables when using categorical variables, nonlinear analysis was performed with vitamin D as the continuous variable. The result showed that the HR of all-cause or cardiovascular mortality decreased with the

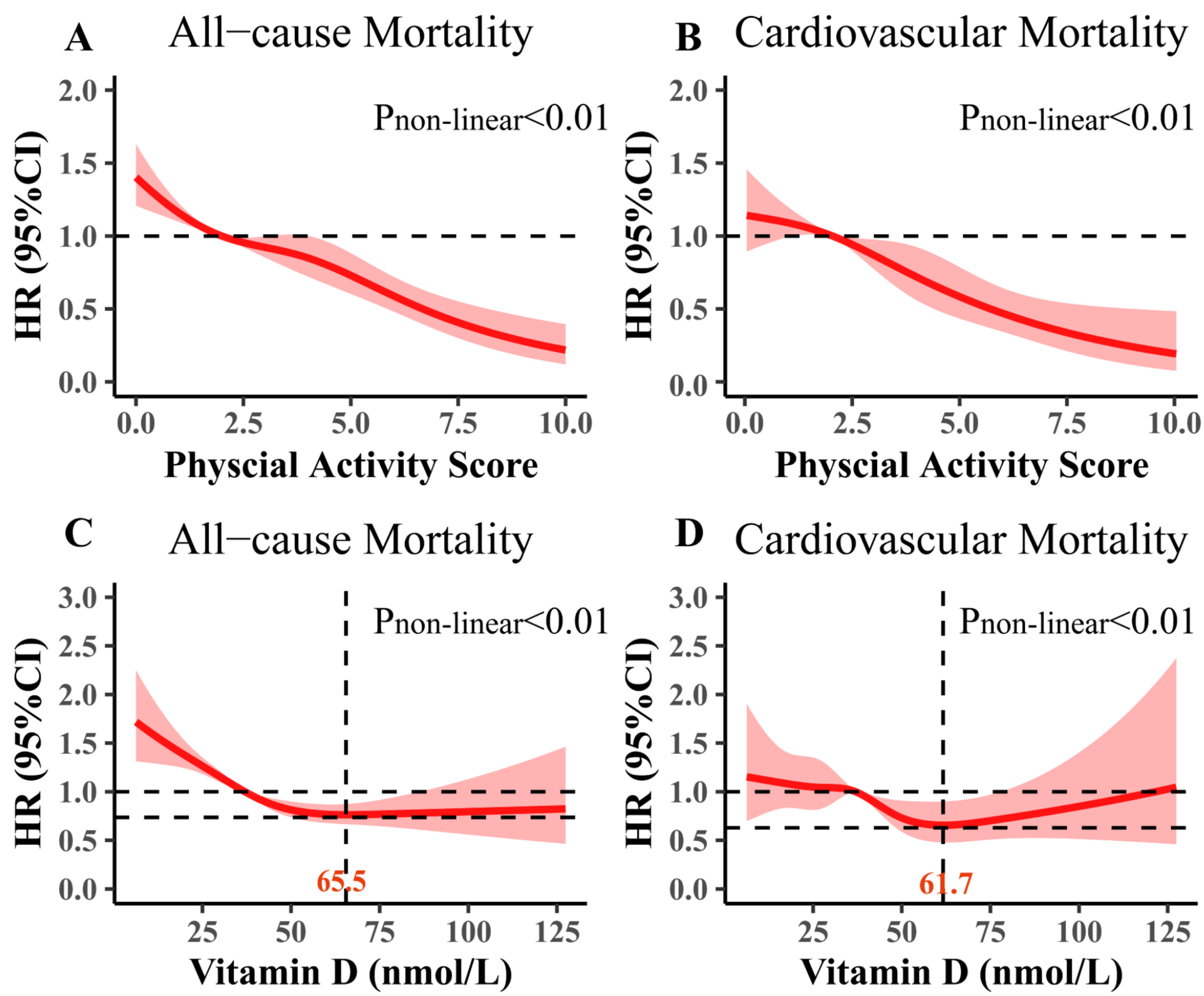

Fig. 3 Association between physical activity score and all-cause/cardiovascular mortality (**A**, **B**). Association between vitamin D concentration and all-cause/cardiovascular mortality (**C**, **D**). All the models were adjusted for age, sex, drinking, smoking, diet, residence, income, marital status, BMI, ADL, morbidity of hypertension, diabetes, heart disease, and stroke. HR, hazard ratio; CI, confidence interval; BMI, body mass index; ADL, activity of daily living

increasing vitamin D level, consistent with the result when vitamin D was treated as the categorical variable. However, HR began to converge to 1 when vitamin D concentration was greater than approximately 65nmol/L (65.5 nmol/L for all-cause mortality and 61.7 nmol/L for cardiovascular mortality, respectively) (Fig. 3C, D).

Stratified and interaction analysis was performed to assess the relationship between vitamin D and all-cause/cardiovascular mortality across different subgroups (Fig. 5). After adjusting for all the variables, the association between high vitamin D levels and all-cause mortality remained significant in almost all subgroups except the city/town. Similar to the stratified analysis of the relationship between physical activity and all-cause/cardiovascular mortality, the protective but insignificant effect was observed in most subgroups at the median vitamin D level except the male, drinking, and rural subgroups. In interaction analysis, none of the variables, such as sex, drinking, smoking, diet, residence, income, marital status, BMI, and ADL levels, showed significant modification of the association between vitamin D and all-cause/cardiovascular mortality.

Mediating effect of vitamin D between physical activity and all-cause/ cardiovascular mortality

The meditation analysis summarized the potential mediating effect of vitamin D between physical activity and all-cause or cardiovascular mortality. Between physical activity and all-cause mortality, the mediation proportions of vitamin D were 9.66% ($P<0.001$) and 7.76% ($P<0.001$) in the unadjusted and adjusted models, respectively (Fig. 6A, B). While between physical activity

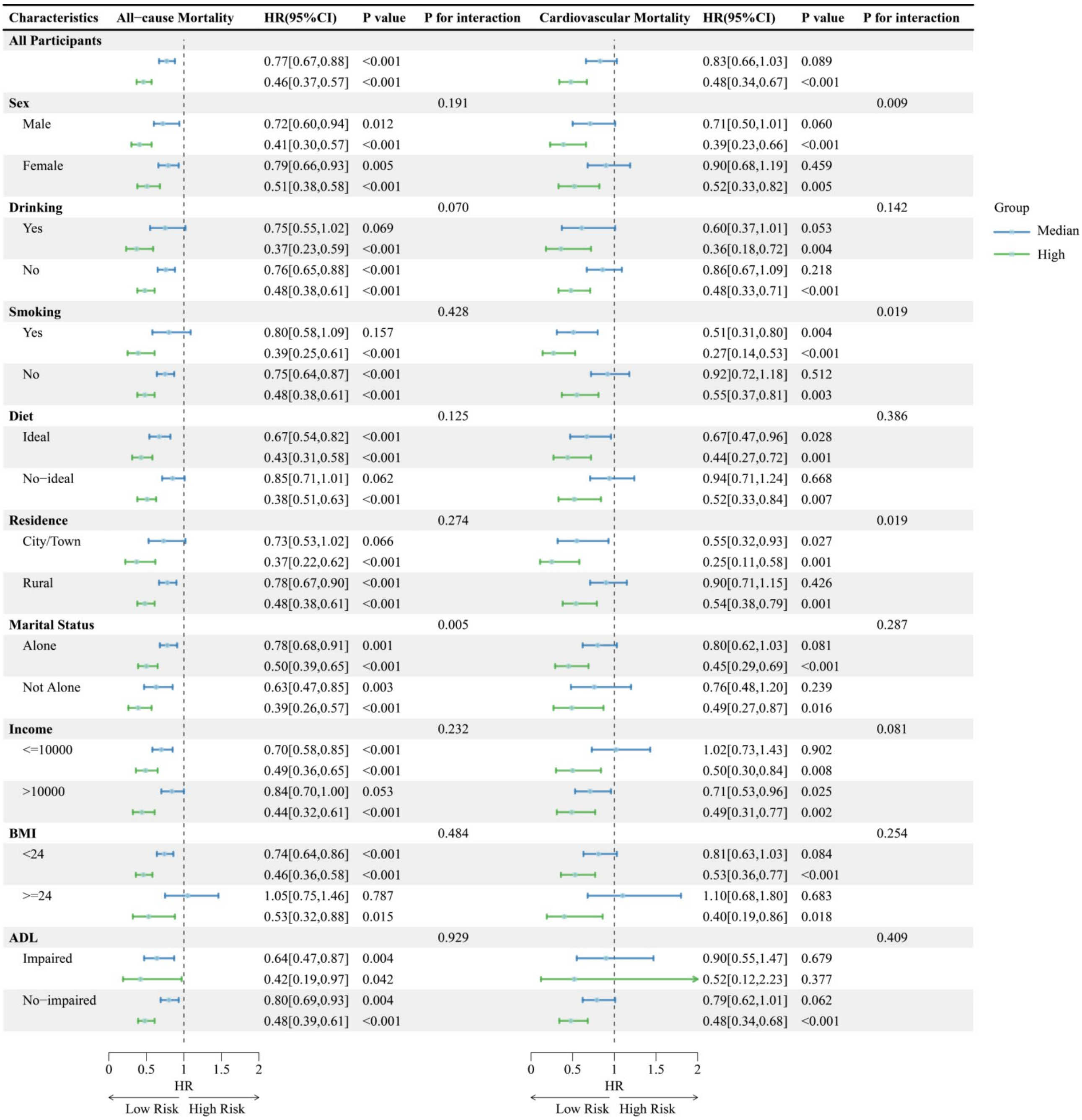

Fig. 4 Stratified analysis of all-cause and cardiovascular mortality hazard ratios according to increased physical activity. The model was adjusted for age, sex, drinking, smoking, diet, residence, income, marital status, BMI, ADL, morbidity of hypertension, diabetes, heart disease, and stroke, except for the strata variable. HR, hazard ratio; CI, confidence interval; BMI, body mass index; ADL, activity of daily living

and cardiovascular mortality, the mediation proportions were 7.61% ($P<0.001$) and 4.13% ($P<0.001$) in the unadjusted and adjusted model, respectively (Fig. 6C, D). To explore the distribution difference of mediating effect in different types of physical activity, we further subdivided the physical activity into regular exercise, housework, growing vegetables/other fieldwork, gardenwork, and raising domestic animals/pets to explore their respective vitamin D mediating effects. The mediating effect of vitamin D remained significant in all types of physical activities ($P<0.001$) (Table 5). The results indicated that vitamin D accounted for the top two mediating proportions in the relationship between housework, raising domestic animals/pets and all-cause mortality (11.16% and 10.40%, respectively). Vitamin D accounted for the top two mediating proportions in the relationship

Table 3 Associations between vitamin D and all-cause/cardiovascular mortality

Vitamin D (nmol/L)	HR (95%CI)					
	All-cause mortality			Cardiovasular mortality		
	Model1	Model2	Model3	Model1	Model2	Model3
Low (<29.57)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Median (29.57–45.74)	0.57*** (0.50,0.65)	0.73*** (0.64,0.83)	0.82** (0.72,0.94)	0.69*** (0.56,0.85)	0.83 (0.67,1.02)	0.94 (0.76,1.16)
High (>45.74)	0.36*** (0.31,0.41)	0.51*** (0.44,0.59)	0.60*** (0.51,0.69)	0.43*** (0.34,0.54)	0.56*** (0.44,0.71)	0.68** (0.53,0.86)
P for trend	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Model 1 was unadjusted

Model 2 was adjusted for age and sex

Model 3 was adjusted for age, sex, drinking, smoking, diet, residence, income, BMI, ADL, morbidity of hypertension, diabetes, heart disease, and stroke

**$p < 0.01$, ***$p < 0.001$

HR, hazard ratio; CI, confidence interval; BMI, body mass index; ADL, activity of daily living

Table 4 Association between physical activity, vitamin D, and all-cause/cardiovascular mortality after using chronological age as the timescale

HR (95%CI)	All-cause mortality			Cardiovasular mortality		
	Low	Median	High	Low	Median	High
Physical activity group	1.00 (reference)	0.73*** (0.64,0.83)	0.45*** (0.36,0.55)	1.00 (reference)	0.79* (0.63,0.98)	0.47*** (0.34,0.66)
Vitamin D	1.00 (reference)	0.77*** (0.68,0.88)	0.56*** (0.48,0.65)	1.00 (reference)	0.89 (0.72,1.10)	0.66*** (0.52,0.84)

All models were adjusted for age, sex, drinking, smoking, diet, residence, income, BMI, ADL, morbidity of hypertension, diabetes, heart disease, and stroke

*$p < 0.05$, ***$p < 0.001$

HR, hazard ratio; CI, confidence interval; BMI, body mass index; ADL, activity of daily living

between raising domestic animals/pets, housework and cardiovascular mortality (6.74% and 6.60%, respectively).

The models were adjusted after adjusting for age, sex, drinking, smoking, diet, residence, income, marital status, BMI, ADL, morbidity of hypertension, diabetes, heart disease, and stroke.

BMI, body mass index; ADL, activity of daily living.

Discussion

Using a nationally representative sample of older Chinese adults, our findings indicated that physical activity could positively affect vitamin D, helping elevate the serum 25(OH)D concentration and reduce all-cause or cardiovascular mortality in older adults. After adjusting for confounding factors, we found that older adults with high physical activity scores tended to have a lower risk of all-cause or cardiovascular disease mortality, and vitamin D might mediate the relationship between physical activity and all-cause or cardiovascular mortality.

Previous prospective studies targeting the pediatric age group from childhood to young adulthood have generally reported protective associations between physical activity and vitamin D with mortality risks, although results were not consistently statistically significant [28, 29]. Many studies have also focused on the relationship between moderate-to-vigorous intensity physical activity and cardiovascular disease mortality [30, 31], but vigorous exercise is hard for older adults. The median age of our studied population was 87 years, and 70.27% were oldest-old. We found a universal benefit to older individuals associated with physical activity, even in terms of not high frequency and intensity of physical activity. The median physical activity level (2–4) could reduce all-cause mortality by 23% and cardiovascular mortality by 17% compared to the low physical activity group (0–1). When physical activity score was used as a continuous variable, we observed that surpassing a threshold of 2.5 indicated a protective effect, with a consequent reduction in all-cause and cardiovascular disease mortality as physical activity score increased. Therefore, our findings supported the hypothesis that keeping a suitable frequency of physical activity can also reduce the risk of all-cause or cardiovascular disease mortality, which expanded on previous studies using an older population sample. According to stratified analysis, our study discovered that the association between physical activity and all-cause/cardiovascular mortality remained significant in most subgroups at high physical activity levels. We also found that physical activity might be more important in decreasing all-cause/cardiovascular mortality in males and people who were not alone, smoking, or in a city/town (P for interaction<0.05).

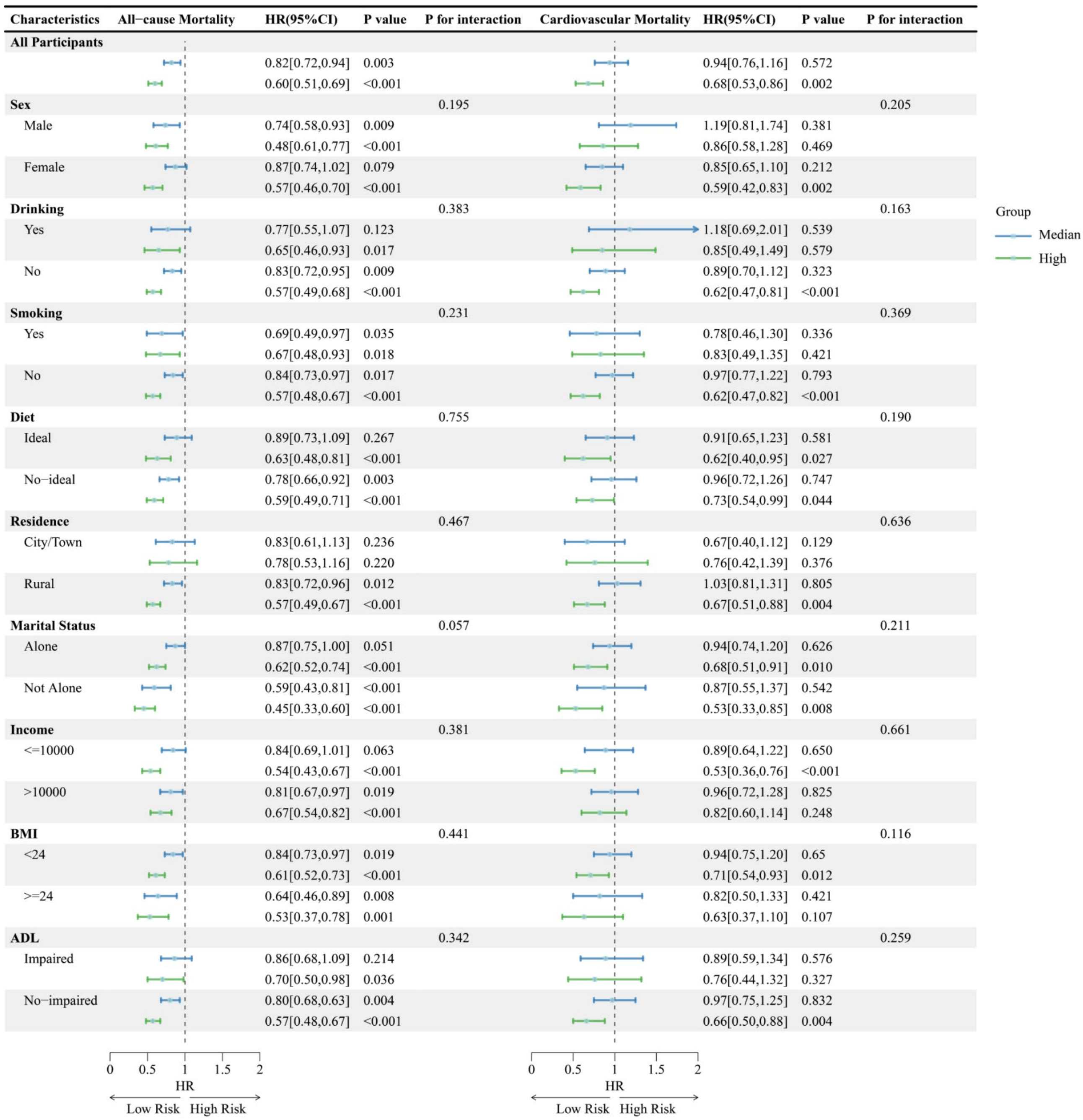

Fig. 5 Stratified analysis of the hazard ratios of all-cause and cardiovascular mortality according to a level increase in vitamin D. The model was adjusted for age, sex, drinking, smoking, diet, residence, income, marital status, BMI, ADL, morbidity of hypertension, diabetes, heart disease, and stroke, except the strata variable. HR, hazard ratio; CI, confidence interval; BMI, body mass index; ADL, activity of daily living

Vitamin D is crucial for maintaining skeletal health and may have other extraskeletal benefits. Observational research indicates that individuals with low vitamin D levels have a higher risk of cancer and cardiovascular mortality [32, 33]. Previous systematic reviews and meta-analysis have revealed that oral vitamin D therapy was linked to a slight decrease in all-cause mortality [34, 35]. However, other trials have failed to demonstrate any beneficial effect of vitamin D supplementation on mortality [36, 37]. Our study found that vitamin D levels were significantly associated with all-cause and cardiovascular mortality in older adults (P<0.001). Furthermore, after treating vitamin D as a continuous variable, we found HR began to converge to 1 when vitamin D concentration was greater than approximately 65nmol/L (65.5nmol/L for all-cause mortality and 61.7nmol/L for cardiovascular

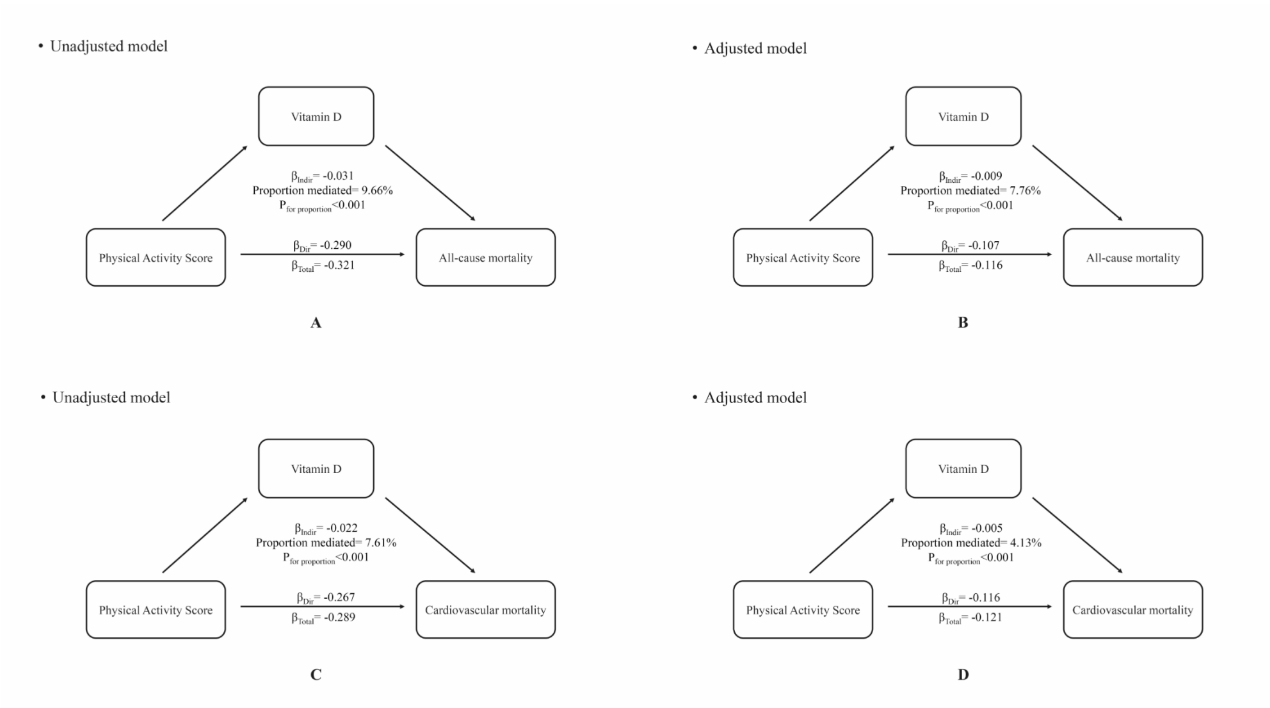

Fig. 6 Mediating effect of vitamin D between physical activity and all-cause/cardiovascular mortality. The model was adjusted for age, sex, drinking, smoking, diet, residence, income, marital status, body mass index, activity of daily living, morbidity of hypertension, diabetes, heart disease, and stroke

Table 5 Meditation analysis among different types of physical activity and all-cause/cardiovascular mortality

Predictor model	All-cause mortality					Cardiovasular mortality				
	βTotal	βDir	βIndir	Proportion	*P* value	βTotal	βDir	βIndir	Proportion	*P* value
Composition of physical activity										
Regular exercise	-0.093	-0.084	-0.009	9.68%	< 0.001	-0.202	-0.195	-0.007	3.47%	< 0.001
Housework	-0.233	-0.207	-0.026	11.16%	< 0.001	-0.212	-0.198	-0.014	6.60%	< 0.001
Growing vegetables/ other fieldwork	-0.134	-0.125	-0.009	6.72%	< 0.001	-0.132	-0.127	-0.005	3.79%	< 0.001
Gardenwork	-0.271	-0.267	-0.004	1.48%	< 0.001	-0.301	-0.299	-0.002	0.66%	< 0.001
Raising domestic animals/pets	-0.202	-0.181	-0.021	10.40%	< 0.001	-0.178	-0.166	0.012	6.74%	< 0.001

mortality, respectively). Therefore, this vitamin D concentration (65nmol/L or so) may serve as a threshold for all-cause and cardiovascular mortality, demonstrating that the higher concentration of 25(OH)D might not further reduce the risk of all-cause or cardiovascular mortality. Recent large-scale studies also found similar results [38, 39]. According to stratified analysis, high vitamin D level (>45.74nmol/l) could reduce all-cause and cardiovascular mortality in all subgroups. Median vitamin D level (29.57-45.74nom/l) could also reduce all-cause mortality in all subgroups, but they did not reduce cardiovascular mortality in some subgroups. This may be caused by the limited sample size. Consistent with physical activity, the vitamin D level in older adults is important for all-cause and cardiovascular mortality.

We investigated the relationship between physical activity scores and vitamin D levels. Boxplot revealed a significant difference in vitamin D levels between different physical activity groups, and nonlinear analysis demonstrated that vitamin D levels increased with physical activity scores. All these findings indicated that increasing physical activity could help to increase vitamin D levels in older adults, similar to former studies [40, 41]. Physical activity involves bodily movements driven by skeletal muscles, leading to higher energy use than resting levels. Conducting physical activities outdoors, especially with sun exposure, offers dual benefits: from the physical activity itself and the production and effects of vitamin D within the body.

Considering physical activity, former studies focused on the mediating role of adiposity, which indicated significance in the relationship between physical activity and vitamin D [15, 42]. Other studies also researched depression feelings in the association between physical activity and disabilities [43, 44]. In our study, we further discovered that physical activity might influence all-cause and cardiovascular mortality partially through vitamin D. Given our study population was older adults (median age 87 years) who could not complete high-intensity/frequency physical activity, supplementing vitamin D might become a method to reduce the risk of all-cause and cardiovascular mortality. Besides, our study discovered that the mediating role of vitamin D showed significance in all types of physical activity. Moreover, vitamin D accounted for the top two mediating proportions between raising domestic animals/pets, housework and all-cause/cardiovascular mortality. Doing housework or raising domestic animals/pets are relatively light physical activities, so for older adults who could only engage in such physical activities, supplementing vitamin D might serve as an approach to reduce all-cause and cardiovascular mortality.

The strength of our study was that we revealed the association between physical activity and all-cause/cardiovascular mortality in older Chinese adults and further revealed the mediating role of vitamin D in the process. In addition, our study discovered that a suitable vitamin D level could minimize all-cause/cardiovascular mortality, and a high vitamin D level might not reduce the risk further. Moreover, the mediation analysis showed physical activity might decrease all-cause/cardiovascular mortality through vitamin D, which could provide a method for older adults to reduce all-cause or cardiovascular mortality. The limitation of our study is that the proportion of the mediation effect of vitamin D was not particularly high. Further study could focus on other mediating roles between physical activity and all-cause/cardiovascular mortality. Besides, despite conducting a comprehensive physical activity score, we still lacked the intensity data of physical activity, which made our findings of positive results from physical activity based on frequency. Finally, our samples included participants from eight longevity areas with blood samples. Compared to the excluded participants, they are older, have better lifestyle habits, and have a lower morbidity of chronic diseases (Supplementary Table 4). This might affect the generalizability of our study results. In future studies, we would also consider using other databases to conduct multiple cohort studies to enhance the sample's representativeness.

Conclusions

Physical activity could reduce the risk of all-cause/cardiovascular mortality and was partially mediated by vitamin D in older Chinese adults. Supplementing vitamin D might reduce all-cause and cardiovascular mortality for older adults, especially those who can only do lighter physical activity like housework or raising domestic animals/pets.

Abbreviations

CLHLS	Chinese Longitudinal Healthy Longevity Survey
25 (OH)D	25-hydroxyvitamin D
ELISA	Enzyme-linked immunosorbent assay system
BMI	Body mass index
HR	Hazard ratio
CI	Confidence interval
IQR	Interquartile range
ADL	Activity of daily living

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-025-05687-1.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

Supplementary Material 6

Acknowledgements

We thank the staff of the Chinese Longitudinal Healthy Longevity Survey for their invaluable contributions.

Author contributions

Y.Z. and M.C. contributed to the concept and design of the study. M.C. performed the data analysis. L.C. and S.Y. revised the manuscript. All authors have reviewed and concurred with the final, published version of the manuscript.

Funding

None to be declared.

Data availability

The original datasets used in this study can be found at the following URL: https://opendata.pku.edu.cn/dataverse/CHADS. Researchers interested in accessing these data can submit a data use agreement to the CLHLS team for approval.

Declarations

Ethics approval and consent to participate

The CLHLS study was approved by the Research Ethics Committee of Peking University (IRB00001052–13074). All participants or their guardians provided written informed consent. The study adhered to the principles of the Declaration of Helsinki. All research procedures were conducted following the established guidelines.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 19 May 2024 / Accepted: 7 January 2025
Published online: 16 January 2025

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